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Climate Variability, Ecosystem Stability, and the Implications for Range and Livestock Development*

James E. Ellis, Michael B. Coughenour,
and David M. Swift

Some long-term trends in ecological theory

In mid-1990, the *New York Times* carried an article entitled 'Balance of Nature Concept Challenged'. This article reported on a symposium at the annual meeting of the Ecological Society of America (ESA), where evidence was presented that 'change and turmoil, rather than constancy and balance are the rule' in nature. This was truly newsworthy, because, for almost 200 years, the concept of the equilibrational nature of natural systems, i.e., the balance of nature, has dominated ecological and evolutionary theory and thought as well as natural resource management. In 1798, Thomas Malthus, 'the first professional economist', initiated what has turned out to be one of the most durable of ecological theorems, namely, that populations are regulated by their food supply, through density-dependent feed-back relationships. Regarding evolutionary theory, Darwin and Wallace simultaneously presented, in the late 1880s, their view of the gradual evolution of species through the orderly processes of competition and natural selection (Darwin, 1859).

Both these evolutionary and ecological precepts are based on an assumption of equilibrium. That is, that conditions outside the system of interest are relatively stable over time, allowing the internal processes of the system to play out or equilibrate, and to regulate system structure and dynamics. Thus, the 1990 ESA symposium, in questioning this 'balance of nature', challenged one of the oldest and most fundamental premises in ecology and evolutionary biology. In fact, challenges to the equilibrational concept and its derivatives have been part and parcel of scientific debates for a long time and many of the dissenting views originated from the field of resource management. And in the last 10-20 years these dissenting voices have coalesced into an alternative concept.

Every range, forest, fisheries, and wildlife ecologist can appreciate that equilibrational concepts have (in addition to their impact on ecological theory) greatly influenced the management of natural resources. Range and livestock management has, for 65 years, been built around the concept of range condition class and the practices of determining carrying capacities and manipulating livestock numbers and grazing seasons to influence range condition. This managerial approach is, of course, derived from the equilibrational or climax concept of Clementsian succession (Clements, 1916).

* This paper is also published in Cincotta et al. 1991.

Although succession, as Clements presented it, was the target of criticisms over many years (Gleason, 1927; Whittaker, 1951; Drury and Nisbet, 1973), it was still the focal concept of ecosystem theory according to Margalef (1968) in the late 1960s, and succession provided the central theme of Eugene Odum's synthetic treatise on the 'strategy of ecosystem development' published in 1969. In this paper, Odum suggested that succession theory might be the 'basis for resolving man's present environmental crisis'. This clearly provided a vote of confidence from a distinguished ecologist for the equilibrational nature of ecosystems and the appropriateness of succession as a foundation for natural resource management. Odum's paper represents a watershed event in ecology, not only because it synthesised half a century of previous successional and ecosystem theory, but also because it marks the beginning of the period (1970-80) when dissatisfaction with this balance-of-nature concept began to condense into an alternative (non-equilibrium) view of the dynamics of ecosystems and the evolution of species.

In the early 1970s, papers began to appear which emphasised neither the systematic and equilibrium nature of ecosystem interactions nor the predictable patterns of successional and evolutionary change. Rather, a different view of nature began to emerge which stressed the random occurrence of external events and the idiosyncratic and unpredictable effects of externalities on ecosystem dynamics and on populations and species. One of the most provocative ideas in evolutionary theory since Darwin was presented by Eldredge and Gould in 1972. In their paper on punctuated equilibria, they hypothesised that extraneous, large-scale, random 'events' have had more influence on the course of evolutionary history than have competitive interactions and the slow, equilibrium fine-tuning of Darwinian natural selection.

Ecologists were also reconsidering the equilibrium nature of ecological systems at this time. In 1973, C.S. Holling reviewed the concepts of stability and resilience in ecological systems; he advocated shifting attention from equilibrium states and interactions to exploring the conditions necessary for system persistence. In Holling's view, resilience to external perturbation and persistence in a changing world are the crucial characteristics of ecological systems. 'Natural, undisturbed systems are likely to be continually in a transient state; they will be equally so under the influence of man' (Holling, 1973:2). Also in 1973, Noy-Meir postulated that dry ecosystems are controlled more by climatic events and sequences than by equilibrating interactions among the biotic components of the system, a distinctly non-equilibrium assertion. However, in later papers he emphasised the role of biotic interactions in causing systems to shift from one stable state to another (Noy-Meir, 1973, 1975; Walker and Noy-Meir, 1982).

Evidence from another set of arid and semi-arid ecosystems caused Weins (1977) to propose that climate, rather than competitive interactions, regulated avian community structure in the grasslands and shrublands of North America. He went on to make the prescient prediction that ecosystems exist along a gradient of conditions, with biotic interactions controlling community

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The relevance of the systems has become evident in pastoralism, Lamprey (1985) is equilibrium in nature, and density-dependent interactions supported by the result of the Serengeti Research (McNaughton, 1985; Duggan) pastoralists often destabilise ecosystems, through overgrazing. Lamprey's experience over the mesic (500-1000 mm rainfall)

A very different view emerged over time by the economist (Holling) observation that as rainfall increases a conservative grazing system of livestock at a safe density can track plant production rates under variable rainfall conditions. His view is equilibrium and reflects Lamprey's ideas are clearly more mesic grazing lands

An extremely thorough study of a system in New South Wales associates (Caughley et al.) climate, plants, sheep, a highly dynamic system over time in both degree and kind (Caughley, 1987:194) and of annual rainfall exceeds the system is better characterised by mean values. Although their results clearly reflect behaviour that some have in this kind of system, this is an abstraction and not a

Our own work in an arid Kenya (summarised by Ewing) hypothesised that the dynamics are controlled by frequent disturbances from equilibrium most unlikely that pastoralism suggested by Lamprey

structure where abiotic variability is small (classical equilibrium conditions), while these same abiotic effects come to control communities when climate is highly variable (non-equilibrium conditions) (Weins, 1984).

The relevance of these concepts to extensive range, livestock, and wildlife systems has become evident in the 1980s. Focusing on African pastoralists and pastoralism, Lamprey (1983) postulated that African savanna ecosystems are equilibrium in nature, and where native wildlife systems exist, stable, equilibrium density-dependent interactions predominate. This premise is generally well supported by the results of several long-term ecological studies conducted at the Serengeti Research Institute (Sinclair and Norton-Griffiths, 1979; McNaughton, 1985; Dublin et al., 1990). Lamprey further suggested that pastoralists often destabilise and degrade these potentially equilibrium African ecosystems, through overstocking and overgrazing. It is important to note that Lamprey's experience was predominantly in Tanzania, in areas of relatively mesic (500-1000 mm rainfall) grazing systems.

A very different view of African pastoral systems was expressed at the same time by the economist Stephen Sandford (1983a). He made the important observation that as rainfall variability increases, so do the opportunity costs of a conservative grazing strategy. Such a conservative strategy would maintain livestock at a safe density, dictated by the long-term carrying capacity of the system. Sandford argued that an opportunistic strategy, in which stocking rates track plant production, was appropriate under highly unpredictable rainfall conditions. His view of pastoral livestock systems is distinctly non-equilibrium and reflects the dynamic nature of arid African ecosystems. Lamprey's ideas are clearly equilibrium and reflective of his experience in the more mesic grazing lands of Tanzania.

An extremely thorough analysis of an arid (>250 mm rainfall) grazing system in New South Wales, Australia, was conducted by Caughley and his associates (Caughley et al., 1987). They evaluated the interactions among climate, plants, sheep, and kangaroos and characterized this arid system as highly dynamic over time. They concluded that 'highly variable systems differ in both degree and kind from slightly variable systems' (Shepherd and Caughley, 1987:194) and suggest that where the coefficient of variation (CV) of annual rainfall exceeds about 30%, then the long-term performance of a system is better characterised in terms of its variability than by measures of mean values. Although they eschew the terms equilibrium and non-equilibrium, their results clearly reflect the climate-driven, dynamic sort of ecosystem behaviour that some have characterized as non-equilibrium. They proposed that, in this kind of system, the concept of an ecological carrying capacity is largely an abstraction and not very useful.

Our own work in an arid (300-400 mm precipitation) region of northern Kenya (summarised by Ellis and Swift, 1988) reached similar conclusions. We hypothesised that the dynamics of the Turkana pastoral ecosystem are largely controlled by frequent drought perturbations and that the system operates far from equilibrium most of the time. Under these circumstances, it seems unlikely that pastoralists would routinely overstock and overgraze as suggested by Lamprey (1983) and many others. We also questioned the

applicability of traditional range management and livestock development procedures under such non-equilibrium conditions.

Alternatively, recent results from a long-term study of Borana pastoralists, conducted in the Southern Ethiopian rangelands by ILCA scientists, support the idea of equilibrium dynamics in pastoral ecosystems. Coppock's chapter in this book reports that in the relatively mesic (400-700 mm rainfall) Ethiopian highlands droughts are infrequent, livestock appear to be near carrying capacity much of the time, and there seems to be a cyclic pattern of overgrazing, bush encroachment and eventual recovery. Under these circumstances it is clear that 'Carrying capacity, successional trends, and density-dependent population dynamics are viable concepts...' (see page 60).

These varied results, ideas, hypotheses, and theories expounded over the last twenty years lead us to the following conclusions:

(i) There is a long-standing and well-established theoretical basis supporting the idea of equilibrium dynamics in ecosystems.

(ii) Our traditional approaches to range management and to livestock development are founded on this theoretical base.

(iii) For many years ecologists and other scientists, especially those working in arid environments, have questioned this theoretical construct. This dissension has led to the development of an alternative theoretical construct, the non-equilibrium hypothesis, to explain the dynamic behaviour of those dry ecosystems.

(iv) Results from studies conducted in arid ecosystems over the last twenty years seem to offer strong support to the non-equilibrium hypothesis.

(v) Up to now, there has not been a well-orchestrated attempt to build a set of management procedures explicitly based on the non-equilibrium hypotheses.

(vi) There remains a division of opinion regarding these alternative hypotheses and appropriate managerial procedures. It is quite clear that Weins (1984) was right when he suggested that we might discover a whole spectrum of ecosystem dynamic behaviour patterns ranging from equilibrium to non-equilibrium.

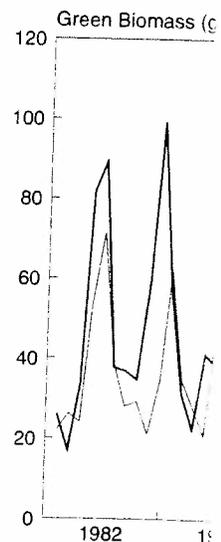
We take encouragement from these varied hypotheses, studies, theories, and ideas. They suggest that ecologists do have the capacity to learn, and that new knowledge and ideas will improve our ability to manage and develop rangeland ecosystems. At this time it seems particularly important to do a better job of identifying the long-term patterns of rangeland dynamics for specific types of ecosystems, and then adapting management and development techniques to fit these dynamic patterns.

Climate variability The northern Ken

Our work in Turkana region where climate is dynamic. Our decade-long study has provided some insight into ecosystem processes, and how pastoralists (Coughlin) respond to perturbations, in the form of livestock numbers, a few years may be a long period when the focus is on the system. For this reason, in this ecosystem, using the data developed from our study.

We tested the plan with actual rainfall records. The vegetation index (NDVI) was used to evaluate the performance of the system exercised using a 65-year term weather data in the region (mean annual rainfall of 2.2), but the patterns of the annual means are

Figure 2.1: NDVI v



**Climate variability and patterns of arid ecosystem dynamics:
The northern Kenya case**

Our work in Turkana District, Northern Kenya, provides an example of a region where climate variability is high and ecosystem behaviour is quite dynamic. Our decade-long study, the South Turkana Ecosystem Project (STEP), has provided some useful insights into how this climatic variability drives ecosystem processes, including the flow of energy from plants to livestock to pastoralists (Coughenour et al., 1985). We have also seen how climate perturbations, in the form of recurrent drought, control plant biomass, livestock numbers, and human exploitation strategies (Ellis et al., 1987). Ten years may be a long time to study a single ecosystem; however, it is a brief period when the focus of interest is the long-term behaviour of the entire system. For this reason we attempted to simulate the long-term behaviour of this ecosystem, using actual precipitation records to drive a simulation model developed from our studies (Coughenour et al., 1990; Swift in Ellis et al., 1987).

We tested the plant production portion of this model by driving the model with actual rainfall records for the period 1981-8. The simulated production sequence was then plotted against remote-sensed normalised difference vegetation index (NDVI) values for the study area during the same period, to evaluate the performance of the model (Fig. 2.1). Next, the model was exercised using a 65-year precipitation record from the only station with long-term weather data in Turkana; this is the district headquarters, Lodwar. The mean annual rainfall for Lodwar over this 65-year period is near 180 mm (Fig. 2.2), but the patterns of variation are more interesting than the mean. The CV of the annual means for this sequence is greater than 60%. Fig. 2.3 portrays

Figure 2.1: NDVI vs. modelled biomass

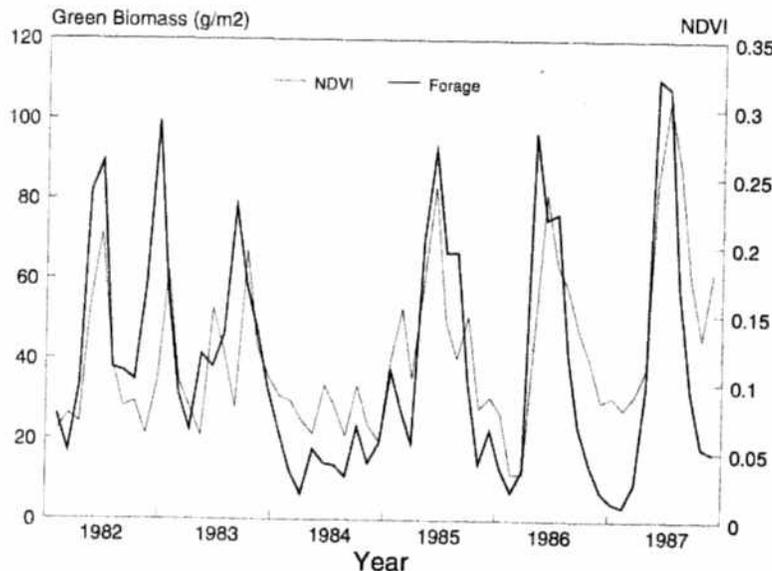
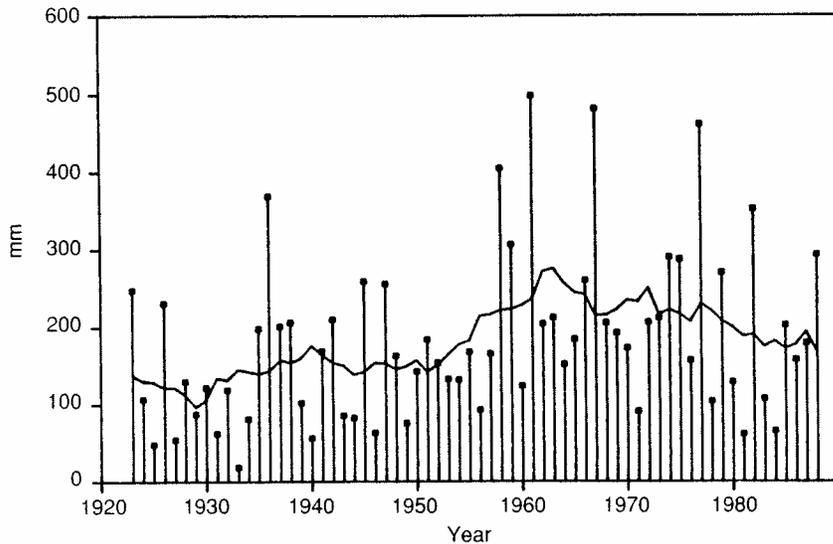


Figure 2.2: Annual rainfall Lodwar, Kenya, 1928-1988, with 3-year running mean

these data as the percentage deviation from the long-term mean. This graph shows a long dry period of roughly 35 years duration, followed by a 20-year sequence of relatively high rainfall with few droughts, and finally a 9-year period with both severe droughts and high rainfall years. Simulation runs covering this period (Fig. 2.4a-d) suggest a very dynamic ecosystem. During the drought of the 1920s and 1930s, the model shows uniformly poor primary production with a resulting very poor livestock condition index. Although modelled plant production improved significantly during the next twenty years, the livestock condition index remained volatile, improving during good rainfall years and declining during droughts. Over the next two decades, until 1979, rainfall was generally good. There was only one drought during the period, and the simulated livestock condition index remained high. It seems possible that livestock numbers may have approached the ecological carrying capacity of the ecosystem at this time. Turkana informants tell us that some pastoralists became semi-sedentary in the early 1970s. This benevolent period ended in 1979-80 at the time when our study began. Since 1980, rainfall patterns have been erratic and the decade has been marked by two droughts, one of which caused livestock mortality on the order of 50% of the regional herd. The modelled livestock condition index reflects the effect of this 2-year drought which occurred early in the decade and resulted in the death of half the regional livestock herd. Interestingly, the more severe but single year 1984 drought caused only a mild decrease in the model livestock condition index; in fact, very few livestock died during the 1984 drought, because of its short duration.

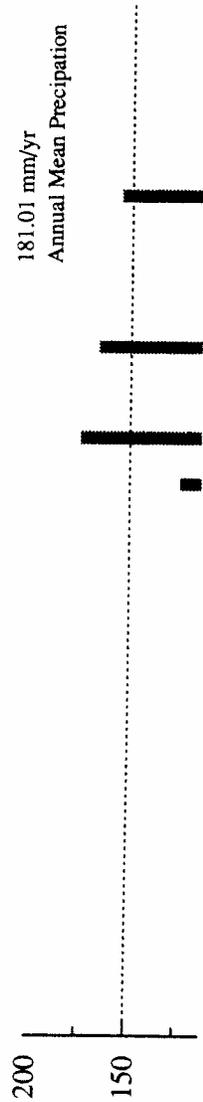
Figure 2.3: Percentage deviation from long-term mean, rainfall at Lodwar, Kenya, 1923-1986

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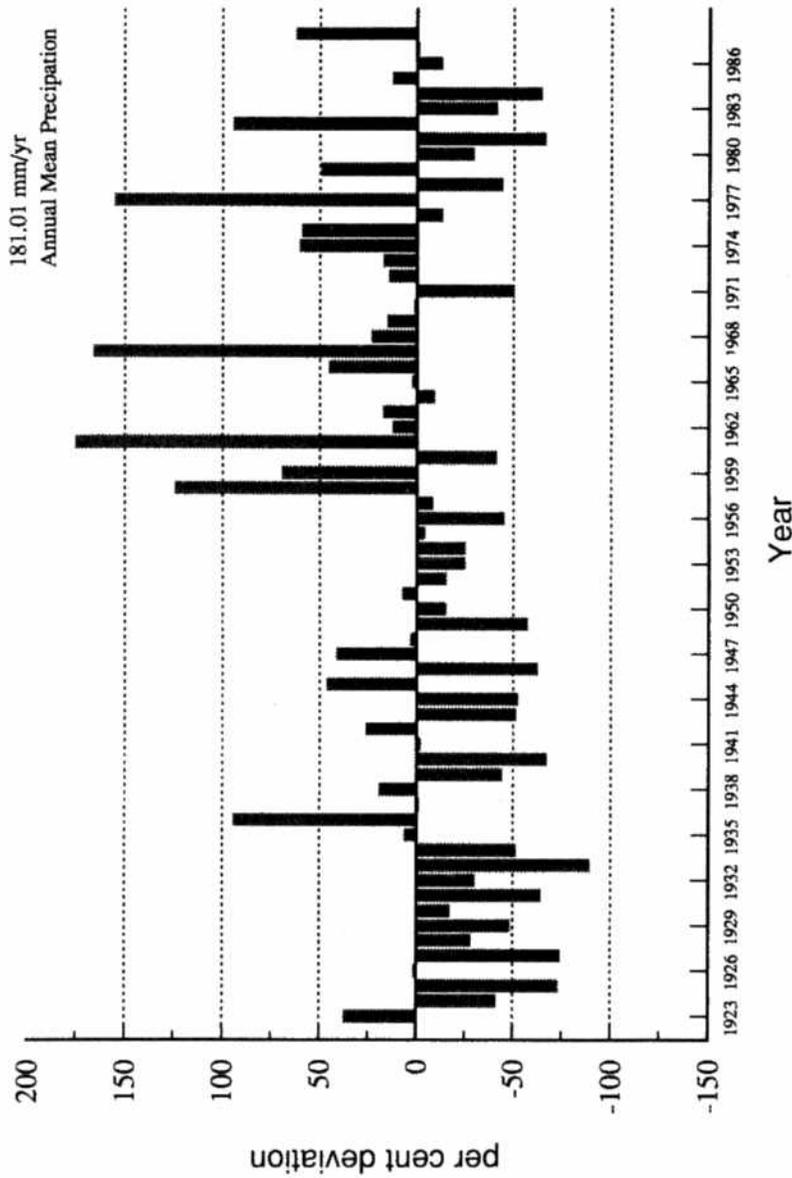
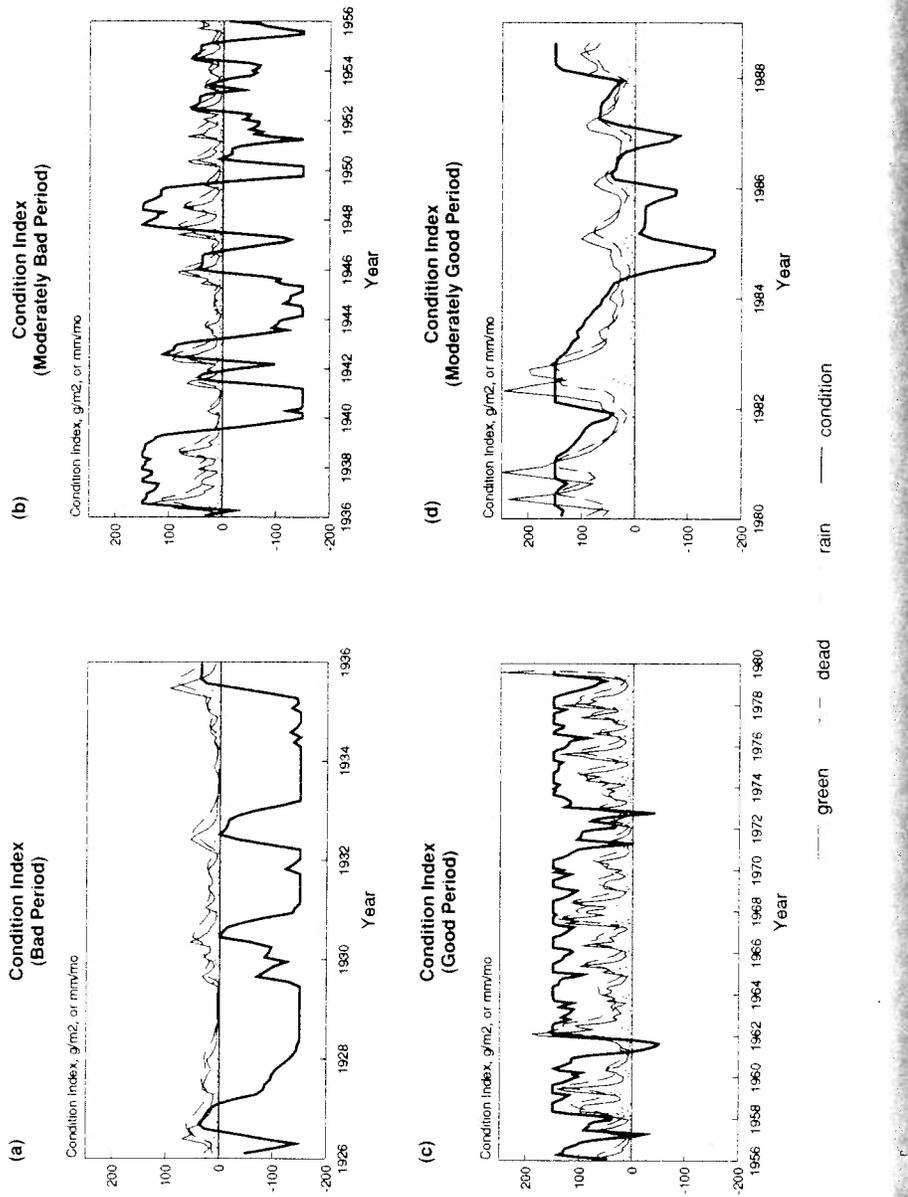


Figure 2.4: Simulated condition index, Lodwar, Kenya, 1926-1988



We believe that this is the STEP study area due to large variations in primary changes in livestock numbers; we are probably correct in an ecosystem, demonstrating that ecosystems might operate true, but only if other attributes from the way the STEP variability are prevalent in Africa as well as in some

We expect that the presented in the results exception for arid ecosystems. Under what climatic conditions occur? Caughley et al. (1983) suggests that a threshold between 300-400 mm rainfall in dry tropics, but what a dynamic behaviour also in regions where grazing in addition to droughts to increase climate variability. Finally, we need to develop how to implement range conditions.

Speculations on the systems

Standard range management theory, an equilibrium to maintain a desirable range, applicability of this concept (Hyder et al., 1966) both working in the dry tropics range management and generalities seem to be

(i) Secondary successional rangelands and in some use hypothetical successional

(ii) Plant production and control of climate in the attributes. However, the

We believe that this simulation study tends to support the hypothesis that the STEP study area demonstrates non-equilibrial dynamics, characterised by large variations in primary production from one year to the next, and volatile changes in livestock numbers. Some of our colleagues grudgingly allow that we are probably correct about Turkana, but suspect that it is an unusual ecosystem, demonstrating idiosyncratic dynamics; they suggest that most other ecosystems might operate in a more normal (equilibrial) fashion. This may be true, but only if other arid ecosystems respond differently to climate variation from the way the STEP region does, because comparable patterns of climate variability are prevalent throughout the Sahel and in the arid parts of southern Africa as well as in some dry temperate zones (Nicholson, 1989).

We expect that the dynamics of the STEP study area are, like those presented in the results of Caughley, et al. (1987), the rule rather than the exception for arid ecosystems. If this is correct, a crucial question to ask is: Under what climatic conditions are these non-equilibrial dynamics likely to occur? Caughley et al. (1987) suggest that CVs of annual rainfall greater than 30% will engender these sorts of dynamics. Coppock's chapter in this book suggests that a threshold for non-equilibrial dynamic behaviour may occur between 300-400 mm rainfall per annum. These may be good estimates for the dry tropics, but what about dry temperate zones where diverse patterns of dynamic behaviour also occur (Weins, 1977, 1984)? What about dry, cold regions where grazing systems are subject to blizzards rather than or in addition to droughts (Goldstein et al., 1990)? Will global climate change increase climate variability and the prevalence of non-equilibrial dynamics? Finally, we need to develop a better idea of how to manage rangelands and how to implement range and livestock development programmes under these conditions.

Speculations on the management of non-equilibrial grazing systems

Standard range management procedures are based on Clementsian succession theory, an equilibrial concept, and are implemented through efforts to maintain a desirable range condition class (Lauenroth and Laycock, 1989). The applicability of this concept to dry rangelands has long been questioned (i.e., Hyder et al., 1966) both on a practical and on a theoretical basis. Scientists working in the dry tropics have begun to rethink the theoretical basis for range management and to suggest alternative concepts and practices. Some generalities seem to be emerging:

- (i) Secondary successional sequences are poorly understood for many dry rangelands and in some cases may not exist. It is impractical therefore to use hypothetical successional sequences as management guidelines.
- (ii) Plant production and community structure seem to be largely under the control of climate in the arid tropics, although herbivores do modify these attributes. However, the herbivores and the herder/managers are often in

a position of responding to externally driven change in the grazing system, rather than manipulating and controlling the system themselves.

(iii) Carrying capacities probably have some utility in highly dynamic systems, but as an abstraction rather than a goal. This is because the capacity is likely to change rapidly both within and between years. Increasing herbivore numbers to track ephemeral upward trends in forage dynamics is difficult in commercial systems and near impossible in subsistence systems. Sustained downward trends in forage dynamics require a rapid response on the part of the herder/manager to avoid herbivore losses.

Taking these kinds of concerns into consideration, Sandford (1983a) and Westoby et al. (1989) have proposed that the operative posture for the management of dry rangelands and livestock is one of opportunism. This is also a characteristic of subsistence pastoralist strategies. In the most direct sense, opportunism means being prepared to respond to the opportunities and difficulties which present themselves. From the viewpoint of development and management, this suggests a strategy which allows for high mobility and rapid de-stocking and re-stocking or other such tactics for dealing with uncontrolled changes in plant community structure and biomass.

One aspect of opportunism which is prevalent in arid subsistence pastoral systems is the reliance on external resources. Just as these systems are driven by externalities (the vagaries of the climate), so they depend on externalities for persistence. The Turkana, for example, obtain external resources during periods of drought stress by taking their animals to regions not grazed during good rainfall years (McCabe, 1987b). This often includes invading the traditional ranges of other tribes in Uganda or Sudan, either by permission or through force of arms. The other major mode of acquiring external resources has traditionally been through livestock raiding. Raiding was prevalent in southern Turkana in the early to mid-1980s, and still occurs in the northern part of the District. In the arid Sahel, pastoralists like the WoDaabe and Fulani have traditionally relied on the acquisition of external resources through trade relationships with farmers from the more mesic portions of the region. Disruption of these trade relationships has meant a serious hardship for these pastoralists over the last two decades (Dupire, 1962; White, 1986).

Trading and raiding have always been important strategies for many pastoral societies in arid lands around the world. This is at least partly because persistence in non-equilibrium systems is difficult; the optimal strategy for pastoral persistence may thus be routinely to exploit the non-equilibrium ecosystem during 'good times' and to obtain external resources when the need arises. If this is so, then the most important single development procedure to promote persistence may be to solidify the connections between these pastoral ecosystems and the sources and sinks of external resources. Nominally, this means facilitating the inflows and outflows of goods and livestock through trade or marketing systems and external economies which can absorb and disperse products to and from pastoral ecosystems as they fluctuate over time.

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Development procedures which may be useful and appropriate in equilibrial systems will often be counterproductive and destabilising in non-equibrial systems. Such destabilising practices would include those which limit the pastoralists' ability to obtain external resources (e.g., confining pastoralists to relatively small ranches or other such schemes) as well as other procedures derived from traditional range and livestock management.

The information presented in this chapter would appear to demonstrate firstly that both equilibrial and non-equibrial dynamics occur in real-world grazing systems, and secondly, that appropriate management and development interventions are different for equilibrial and non-equibrial ecosystems. It necessarily follows that scientists, managers, and developers must understand which kind of system they are working with if their efforts are to be successful rather than counterproductive.